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Casting a long shadow in the classroom

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Casting a long shadow in the classroom

An educator's perspective of the contributions of Carl Woese

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"What does one do when the giants pass away?" remarked a very famous microbiologist to me, soon after the death of Carl Woese in late 2012. I teach microbiology and introductory cell and molecular biology at a small undergraduate institution; Woese's example and contributions have long been part of every class I teach, and with good reason. Thus, I didn't know quite what to say to my colleague at first; I was still mentally processing the event.

I am not a premier researcher at a major university, nor did I know Carl Woese beyond two short conversations in the 1990s. But I had watched Woese's contributions rise from a controversy played out in the pages of the Proceedings of the National Academy of Science (as seen in refs. 1 and 2, for example) and elsewhere to an accepted paradigm-shifting viewpoint describing the relationships between all living things.[3,4] There have already been a number of elegant and insightful remembrances of Carl Woese and his many contributions to a variety of areas in biology (see refs. 5–10); I can do little to add to the vivid personal and professional portrait they paint.

However, I would like to describe how important I believe the example and science of Carl Woese has been, and will continue to be, in the undergraduate biology classroom at undergraduate institutions such as my own. I believe that knowledge of history is central, even in science, and Woese's path in biology is instructive of the process and practice of biology. I feel that Woese's greatest contribution, the articulation of the "Tree of Life" based upon 16s rRNA analysis, is matched by his single-minded pursuit of his goals. Thus, I try to impress upon students not only the paradigm shift that Woese and his colleagues created in the way we look at all living things, but also the process and practice of science itself. Science is an innately human profession, and students often perceive its practice as experiments performed in isolation, with a focus on techniques and data interpretation, rather than the work of very human experimenters.

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Carl Woese indeed made remarkable contributions in a number of areas of biology during his life, and the world is a poorer place without his example and (usually) polite and implacable refusal to intellectually "knuckle under" to convention or criticism. Instead, he continued his work and the exposition of what it meant to his field, eventually gaining acceptance of his ideas by the scientific community. I have long used the 1998 American Society for Microbiology sponsored video (http://www.microbeworld.org/podcasts/podcasts/intimate-strangers-unseen-life-on-earth/program-one-the-tree-of-life/261-solving-the-puzzle-part-2-of-10) to illustrate for students Carl Woese (partly in his own words) as a polite, human, driven, and "devoted to the data" type of investigator. There is a saying that change can be evolutionary or revolutionary; the former is usually slow, while the latter can often be metaphorically bloody. It is also true in science, and in some ways, Carl Woese experienced both.

Even a cursory study of the career of Carl Woese shows, despite resistance to his initial proposal that the Archaea comprise a third domain of life,[11] he had been honored with every major award a microbiologist could receive, short of the Nobel Prize. Many people, myself included, felt his contributions were sufficiently important and broadly applicable to merit that recognition as well. One of my goals in teaching about Carl Woese is to show students how his work has become integral to many other areas of biology, ranging from scientific philosophy to experimental procedure, from evolution to medicine. Relevant to my own junior and senior level course, Woese certainly transformed the field of microbiology from an essentially descriptive discipline to one based on evolution and genetic interrelatedness.

Carl Woese is one of the names that I insist my students know and respect—not just in my microbiology course, but in my introductory cell and molecular biology course as well. Again, it is not simply about the Tree of Life, central and important as "the Big Tree" is to biology. It is also about the process that led to the acceptance of the data that Carl Woese collected and interpreted, and how he personally walked that path. Thus, I have students not only watch the video mentioned earlier, to hear how Woese described his own work, but I spend some time describing how Woese and co-workers converted a series of ribonuclease-generated spots on an autoradiograms into a new way to view taxonomy and the universality of life.

Woese's (and his co-workers') insight that the archaea are as different from bacteria as bacteria are different from eukaryotes

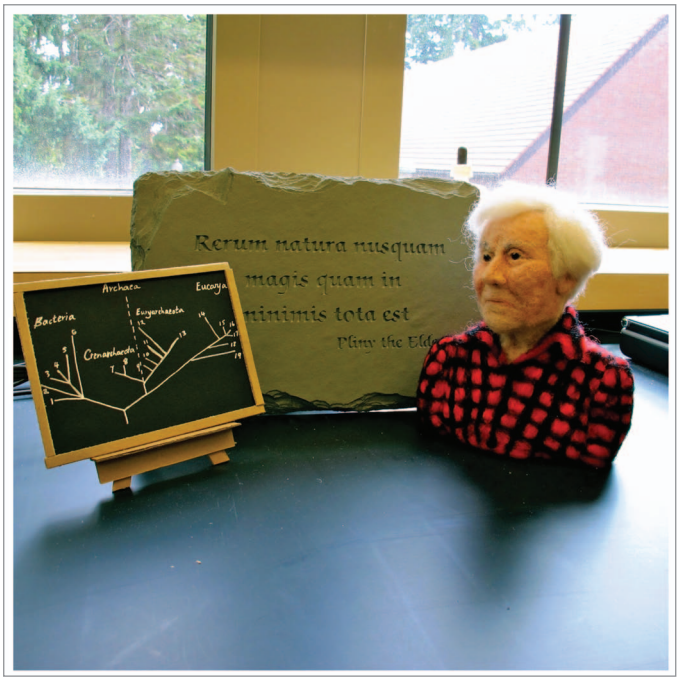

Figure 1. A felt "sculpture" of Carl Woese made in 2012 by the artist Amy Wright, next to a drawing of the 16s rRNA based Tree of Life. The inscription on the stone behind the sculpture is from Pliny the Elder, and reads: "Nature is to be found nowhere more than in Her smallest creatures."

Figure 2. A "portrait" of Carl Woese made with a liquid culture of luminous bacteria (*Photobacterium leignothi*) in 2012. The culture was "painted" using a sterile brush onto the surface of a petri dish containing marine microbiological agar by Jennifer J Quinn and photographed by its own luminescence.

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was fundamental, and not universally accepted at first. As mentioned earlier, Woese experienced a number of eminent scientists disagreeing with him quite forcefully regarding the Three Domains model, including very famous names such as Salvador Luria and the formidable Ernst Mayr. The long-term disagreements between some of these scientists was not altogether professional from time to time, and that aspect of the paradigm shift clearly had an effect on Woese personally, leading one journalist to dub him "microbiology's scarred revolutionary."[12] Once again, science is a human profession, and I find that students are interested in hearing about the "sociology" of science as inferred from journal articles, and investigating the path that leads from a laboratory notebook to accepted dogma in a textbook. Part of this includes learning about the very human side of researchers; for example, my students were amused and even charmed by Woese's self-described "principle of dynamic incompetence"[9] strategy to avoid mundane tasks that took him away from his research, as well as his love of jazz music.

The way in which a paradigm shifts in science has been described many times, and I am not a historian of science. Still, I am reminded of J.B.S. Haldane's waggish but too-often sadly accurate update of Agassiz's view of how science progresses by successive stages:[13]

"Theories have four stages of acceptance. (1) this is worthless nonsense; (2) this is an interesting, but perverse, point of view; (3) this is true, but quite unimportant; (4) I have always said so."

The challenge can be seen as waiting out the transitions between these so-called stages. Thus, I deeply admire Carl Woese's work, and the philosophy and unwavering drive behind that work, as I do the work of Peter Mitchell in promoting the concept of chemiosmosis and cellular energetics, and Lynn Margulis with endosymbiosis and the origins of chloroplasts and mitochondria. When resistance was encountered, Woese continued to work and promote his findings, filling in gaps, and evaluated each data set as he collected it.

I think it is a fair statement that I tend to bring up Carl Woese and his contributions in my classroom often, and in various ways. On my office desk I have a felt "sculpture" of Woese and a stylized diagram of the Tree of Life (**Fig. 1**). For Halloween one year, I showed my classroom a "painting" of Woese using luminescent bacteria as "paint," photographed by its own light (**Fig. 2**). And it is perhaps not surprising that students respond to my presentations in creative ways of their own. **Figures 3 and 4** show students costumed as Carl Woese for a Halloween-themed lecture in the former, and as an "actor" in a parody video in the latter.

This semester, after the readings and discussion in lecture, I handed out an assignment, asking the students to describe in writing how they would describe the life and contributions of Carl Woese to science. In particular, I asked the students to describe Woese in one word, and then I assembled their responses into a "word cloud," which can be seen in **Figure 5**. It was gratifying to see that my students and I agreed on the impact of Carl Woese on microbiology and biology in general. Note how frequently "persistence," "revolutionary," and "fundamental" occur in the word cloud (along with "innovative," "visionary," and "radical"), demonstrating that the students

Figure 3. A student "dressing up" as Carl Woese for Halloween 2012 in my Microbiology course at the University of Puget Sound (next to a student costumed as C.B. van Niel).

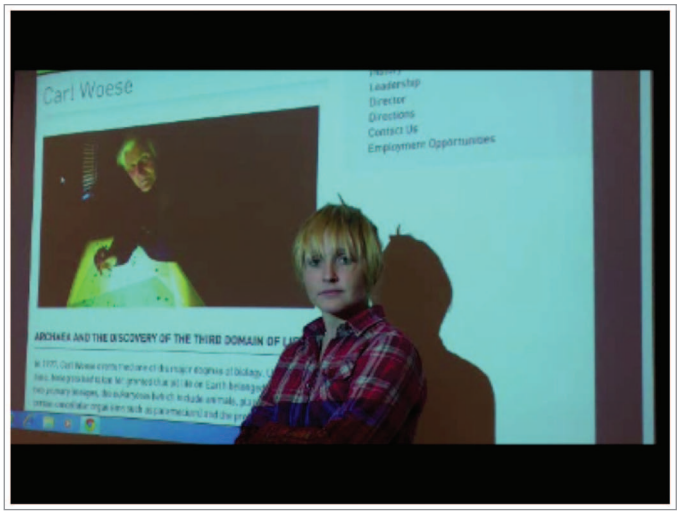

Figure 4. A frame from a student-made "music video" about Carl Woese and his contributions to phylogenetics and taxonomy from my 2013 Microbiology course at the University of Puget Sound.

understood the long yet eventually successful process of acceptance of Woese's ideas. Because I spent some time explaining how 16s rRNA was analyzed in those "pre-DNA sequencing times," I was personally pleased to see "puzzlemaster" appear among the students comments!

The comments made by the students, as they reflected on what they had learned regarding Carl Woese over the semester, were instructive. One student, thinking about what she had learned in other classes, called Woese perhaps "the most underappreciated scientist of our time." Another student appreciated the late scientist's pithy ways of answering questions (when asked to define life, Woese is said to have responded "We can't. That's the problem."). Woese's example reminds science of "the importance of original thought," opined another student. A fourth student was struck by how applicable Woese's work has been to so many areas of biology, making clear the interconnectedness between fields from the molecular to the ecological. It was thus clear to me that the students in my classroom had come to see the impact and relevance of Carl Woese's work and approach to the overall field of biology, and several remarked to me that they hoped that his contributions would be more emphasized in freshman classes.

I will continue to champion Carl Woese's name and contribution in my classes, both for freshmen and for seniors. With my students, I cannot overemphasize the centrality of the paradigm shift the work of Woese generated, put simply: it has fundamentally changed the way we look at the relationships between all living things. And in so doing, he created the backdrop necessary for so much of the current furious ferment in microbiology. In the video referenced above, Norman Pace suggests that Carl Woese has made an impact on biological thinking to rival that of Charles Darwin. Personally, I believe there is a case to be made for this point of view. Perhaps not all biologists think so now. But change is sometimes, as I wrote above, evolutionary. My money is on Carl Woese, as usual.

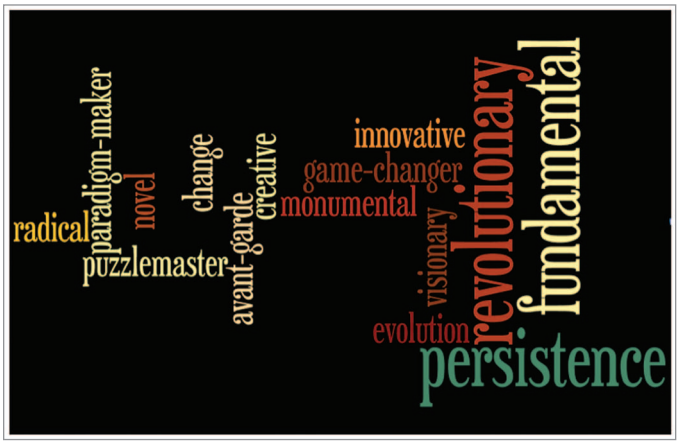

Figure 5. A "word cloud" generated from undergraduate student responses to the perception of Carl Woese's work from a 2013 junior/senior level Microbiology course at the University of Puget Sound. The size of the word relates to the frequency of its occurrence in the student responses.

I think about the world of microbiology without Carl Woese, and feel the loss acutely. But I am reminded of the following passage, from the late Ray Bradbury's novel, *Fahrenheit 451*:[14]

"Everyone must leave something behind when he dies... Something your hand touched some way so that your soul has somewhere to go when you die...It doesn't matter what you do, so long as you change something from the way it was before you touched it into something that's like you after you take your hands away."

As I discuss Woese and his contributions with my students, I often think about the original Five Kingdoms and other early taxonomic plans. I then begin thinking about how Woese and his co-workers began puzzling together those spots of radioactive fragments of 16s rRNA on the autoradiographic films, assembling them by hand, bit by bit, into the Tree of Life with the

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Three Domains we know today. And finally, I invite my students to consider the pervasive and long "shadow" that Woese's seminal work casts across modern biology.

This brings us back to the original question put to me at the beginning of this essay: what do I do when the giants pass away? I will see Carl Woese's face in the metaphoric bark of that three domain Tree of Life, every time I look at it, demonstrating the interrelatedness of all living things, as well as Woese's example of the practice of science. I will make certain that my students see his face and impact, too. Carl Woese leaves a remarkable and lasting legacy, indeed.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest disclosed.

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